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Quarkonia production in proton-lead collisions at LHCb

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ABSTRACT

The production of J/ψ and $\Upsilon(1S)$ mesons decaying into dimuon final state is studied at the LHCb experiment, with rapidity $1.5 < y < 4.0$ or $-5.0 < y < -2.5$ in proton-lead collisions at a nucleon-nucleon centre-of-mass energy $\sqrt{s_{NN}} = 5$ TeV, based on a data sample corresponding to an integrated luminosity of 1.6 nb^{-1} . The nuclear modification factor and forward-backward production ratio are determined for prompt J/ψ , J/ψ from b -hadron decay and $\Upsilon(1S)$ mesons in study of the cold nuclear matter effects.

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1 Introduction

Heavy quarkonia states are good probes to quark-gluon plasma (QGP) in ultra-relativistic heavy-ion collisions, since their production is suppressed with respect to pp collisions due to the formation of QGP. This effect is difficult to disentangle from cold nuclear matter (CNM) effects, such as nuclear shadowing and energy loss of heavy quark (pairs), which also cause suppression of quarkonia production. The proton-nucleus (pA) collisions provide unique environment to study CNM effects with the absence of QGP.

The LHCb detector collected a data sample corresponding to an integrated luminosity of 1.6 nb^{-1} in $p\text{Pb}$ collisions at the LHC. The centre-of-mass energy of the NN system $\sqrt{s_{NN}}$ is around 5 TeV. Two beam configurations are used to cover different rapidity regions: the forward and the backward. The forward region corresponds to $1.5 < y < 4.0$ in the NN center-of-mass frame, with the proton beam pointing towards the detector; on the contrary the proton beam pointing away from the detector corresponds to the backward rapidity region, with $-5.0 < y < -2.5$ in the NN rest frame. Using the data sample LHCb studies the production of J/ψ [1] and Υ mesons[2] in $p\text{Pb}$ collisions at $\sqrt{s_{NN}} = 5 \text{ TeV}$.

2 Production cross-section of J/ψ and Υ mesons

Both J/ψ and Υ mesons are reconstructed with dimuon final states. The trigger and selection efficiencies are determined with data-driven methods wherever possible.

Thanks to the excellent vertexing performance, the LHCb detector is able to distinguish prompt J/ψ mesons and those from b decays according to their pseudo-proper time distribution. The integrated production cross-sections with $p_T < 14 \text{ GeV}/c$ are determined to be:

$$\begin{aligned}\sigma(\text{prompt } J/\psi, 1.5 < y < 4.0) &= 1168 \pm 15 \pm 54 \mu\text{b}, \\ \sigma(\text{prompt } J/\psi, -5.0 < y < -2.5) &= 1293 \pm 42 \pm 75 \mu\text{b}, \\ \sigma(J/\psi \text{ from } b, 1.5 < y < 4.0) &= 166.0 \pm 4.1 \pm 8.2 \mu\text{b}, \\ \sigma(J/\psi \text{ from } b, -5.0 < y < -2.5) &= 118.2 \pm 6.8 \pm 11.7 \mu\text{b},\end{aligned}$$

where the first uncertainty is statistical and the second is systematic, as followed in the rest of the proceeding. The differential production cross-sections of prompt J/ψ and J/ψ from b decay as functions of p_T or y are also measured.

For Υ mesons with $p_T < 15 \text{ GeV}/c$, the integrated production cross-section times the decay branching fraction are measured with limited statistics:

$$\begin{aligned}\sigma(\Upsilon(1S), -5.0 < y < -2.5) \times \mathcal{B}(1S) &= 295 \pm 56 \pm 29 \text{ nb}, \\ \sigma(\Upsilon(2S), -5.0 < y < -2.5) \times \mathcal{B}(2S) &= 81 \pm 39 \pm 18 \text{ nb}, \\ \sigma(\Upsilon(3S), -5.0 < y < -2.5) \times \mathcal{B}(3S) &= 5 \pm 26 \pm 5 \text{ nb}, \\ \sigma(\Upsilon(1S), 1.5 < y < 4.0) \times \mathcal{B}(1S) &= 380 \pm 35 \pm 21 \text{ nb}, \\ \sigma(\Upsilon(2S), 1.5 < y < 4.0) \times \mathcal{B}(2S) &= 75 \pm 19 \pm 5 \text{ nb}, \\ \sigma(\Upsilon(3S), 1.5 < y < 4.0) \times \mathcal{B}(3S) &= 27 \pm 16 \pm 4 \text{ nb},\end{aligned}$$

where $\mathcal{B}(nS)$ denotes the branching fraction of $\Upsilon(nS) \rightarrow \mu^+ \mu^-$ ($n = 1, 2, 3$) decay. All the measurements above assume that J/ψ and Υ mesons are produced with no polarisation.

3 Cold nuclear matter effects on J/ψ and Υ production

The cold nuclear matter effects can be characterised by nuclear modification factor $R_{pA} \equiv \frac{1}{A} \cdot (\frac{d\sigma_{pA}}{dy}) / (\frac{d\sigma_{pp}}{dy})$ and the forward-backward production ratio $R_{FB} \equiv \sigma_{pA}(+|y|) / \sigma_{pA}(-|y|)$. With the production cross-sections measured in forward and backward rapidity regions as introduced in the previous section, the CNM effects on prompt J/ψ , J/ψ from b decay and $\Upsilon(1S)$ mesons can be studied ($\Upsilon(2S)$ and $\Upsilon(3S)$ yields are too low).

To determine the nuclear modification factor it requires cross-sections at $\sqrt{s} = 5$ TeV in pp collisions as a reference, which is obtained by interpolating from J/ψ and $\Upsilon(1S)$ productions at 2.76 TeV, 7 TeV and 8 TeV pp collisions measured by LHCb [3, 4, 5, 6, 7].

The measured nuclear modification factors for J/ψ are shown in Figure 1. The R_{pPb} are measured for prompt J/ψ and J/ψ from b decays separately, because the latter reflects the CNM effects on b hadrons rather than J/ψ itself. Strong suppression for prompt J/ψ production in forward region is observed, while the suppression of J/ψ from b is modest, indicating the CNM effects on b hadrons are less prominent. The forward-backward production ratios as a function of rapidity are shown in Figure 2. It confirms the suppression of prompt J/ψ in the forward region, especially at large rapidity; while the asymmetry of J/ψ from b decay is smaller. The theoretical predictions [8, 9, 10, 11] generally agree with measured results, within large uncertainties.

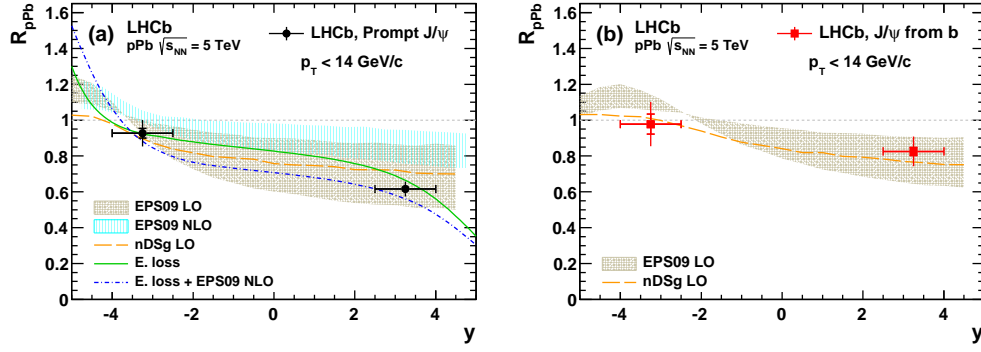


Figure 1: Nuclear modification factor (top) and forward-backward production ratio (bottom) of (left) prompt J/ψ and (right) J/ψ from b decay as a function of rapidity.

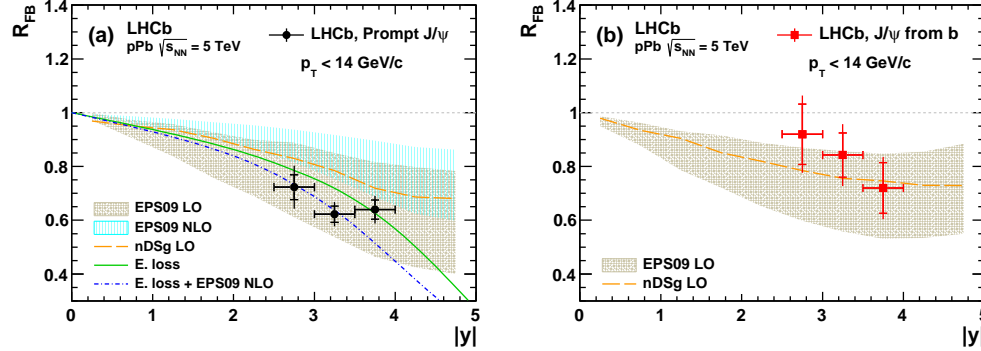


Figure 2: Forward-backward production ratio of (left) prompt J/ψ and (right) J/ψ from b decay as a function of rapidity.

The measured R_{pPb} and R_{FB} for $\Upsilon(1S)$ as functions of rapidity are shown in Figure 3 and 4 respectively, with J/ψ results and each panel a theoretical calculation [9, 10, 12] for comparison. The suppression of $\Upsilon(1S)$ production in the forward region is smaller than prompt J/ψ , and close to J/ψ from b decay. This indicates that the CNM effects on $\Upsilon(1S)$ is similar to that on b hadrons. Due to large uncertainties all theoretical models are consistent with data.

4 Conclusions

The production of prompt J/ψ , J/ψ from b decay and Υ mesons at $\sqrt{s_{NN}} = 5$ TeV in pPb collisions are measured at LHCb, in rapidity range of $-5.0 < y < -2.5$ and $1.5 < y < 4.0$. The cold nuclear matter effects

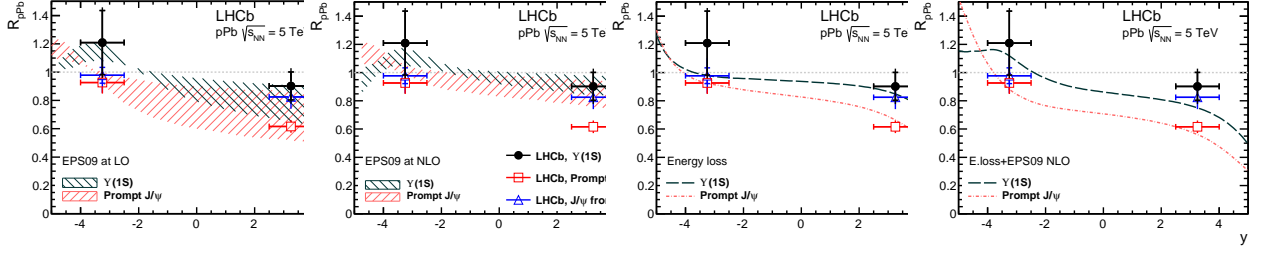


Figure 3: Nuclear modification factors for prompt $\Upsilon(1S)$ and J/ψ as a function of rapidity, comparing with different theoretical calculations.

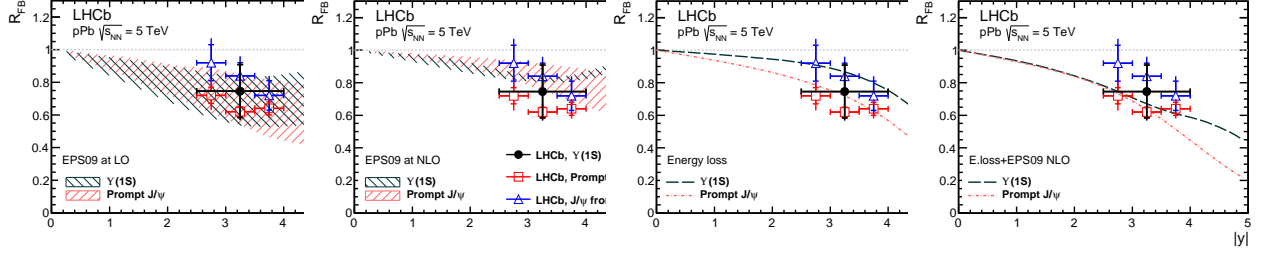


Figure 4: Forward-backward production ratio for prompt $\Upsilon(1S)$ and J/ψ as a function of rapidity, comparing with different theoretical calculations.

are studied by measuring nuclear modification factors R_{pPb} and forward-backward production ratio for these mesons. It is observed that prompt J/ψ production is strongly suppressed in the forward region. The cold nuclear matter effects on $\Upsilon(1S)$ and J/ψ from b hadrons are similar, both smaller than prompt J/ψ .

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